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Summary of Research
(May 1, 1968 - October 31, 1968)

The major goals of this research are to generate a deep understanding of communication channels and sources and to use this understanding in the development of reliable, efficient communication techniques.

1. Optical Communication

The fundamental limitations and efficient utilization of optical channels are the general concern of these investigations. Our interests include the turbulent atmospheric channel, the cloud transmission channel, quantum-limited channels, and scatter channels. The investigations range from channel modeling issues through feasible near-optimum communication systems to fundamental coding theorems.

The performance limitations imposed by atmospheric turbulence in the absence of quantum effects has been determined.^{1,2} The optimum receiver for this channel differs from those normally employed in that it utilizes the spatial diversity inherent in the fluctuations of the field across the receiving aperture. Since a receiver which utilizes this diversity in the most straightforward way is often extremely complicated, we have examined the field fluctuations for structure that might be cleverly exploited by the receiver. Suitable structure has been found over relatively small apertures.^{3,4} In particular, the field is reasonably modeled as a superposition of a few non-uniform plane waves. The development of relatively simple near optimum receivers continues.

A doctoral level investigation of the limitations imposed by the turbulent atmosphere upon high resolution astronomy, or surveillance, has also been completed.⁵ The principal conclusion is that significant gains in performance can be realized for "bright" objects through the use of data processing techniques suggested by statistical estimation theory. However, these techniques involve a substantial amount of data processing.

In other areas, three doctoral level investigations have been completed. One of these is concerned with the structure and performance of optimum quantum receivers for random phase and for fading channels used in conjunction with orthogonal waveform alphabets.⁶ Analytical descriptions of the receivers have been developed and exponentially correct bounds to the error probability have been determined. One conclusion has been that quantum effects cannot be accounted for by an additive "quantum" noise.

The limitations upon the transmission of information by combined temporal and spatial modulation, e.g., by a sequence of "images", is the subject of another completed doctoral thesis.⁷ The fundamental relationships between time, bandwidth, aperture size, and background noise were of particular concern in this investigation. A principal result has been a more complete understanding of the number of degrees of freedom contained within a specified region of the time-frequency-space domain.

A model for communication through clouds has been developed in a third doctoral thesis.⁸ Among the principal results were the conclusion that the received process is Gaussian and a determination of the amount

of spatial diversity inherent in the channel; The performance of cloud channels when the noise is adequately described by an additive white Gaussian process was also determined.

2. Coding for Noisy Channels and for Sources

A doctoral thesis on systematic convolutional codes and on the sequential decoding of systematic convolutional codes has been completed.⁹ Earlier results¹⁰ showed that with maximum-likelihood decoding, the exponential dependence of error probability on code constraint length for systematic codes is a fraction $m/(m+1)$ of that for nonsystematic codes, where m is the number of check digits per information digit in the code. Later results show that the error probability for sequential decoding of systematic convolutional codes is considerably higher than the error probability for maximum-likelihood decoding and indicate that under most circumstances, nonsystematic codes should be used in sequential decoding applications.

Another doctoral research project is centered around the problem of transmitting a discrete-time Gaussian source over an additive white Gaussian noise channel with a mean square error criterion. It has been shown that if the successive source samples are independently processed for transmission, by any means at all, the resulting mean square error, in the limit of high signal to noise ratios, must be at least 6 db higher than the minimum mean square error achievable with joint processing of the source samples. It has also been shown that a process essentially equivalent to discrete time FM and to PPM yields a mean square error

approximately 8db¹ higher than the minimum achievable with joint processing. Work is progressing on the case of smaller signal to noise ratios and on achieving a closer tie into classical modulation theory.

A text book¹¹ on Information Theory and coding techniques has also been completed. Along with providing simple treatments of the well-known results in the field, the book gives cohesion to many previously disjoint topics and presents numerous previously unpublished research results.

References

1. R. S. Kennedy and E. V. Hoversten, "On the Atmosphere as an Optical Communication Channel," IEEE Transactions on Information Theory, Sept. 1968.
2. Seppo Halme, "Efficient Optical Communication Through a Turbulent Atmosphere", M.I.T. RLE Quarterly Report No. 91, November 15, 1968.
3. J. H. Shapiro, "A Plane Wave Model for a Turbulence-Corrupted Laser Beam," S.M. thesis, Department of Electrical Engineering, M.I.T., September 1968.
4. J. N. Bucknam, "The Transmitted Reference Optical Communications System: Its Performance in the Turbulent Atmospheric Channel," S.M. thesis proposal, Department of Electrical Engineering, M.I.T.
5. J. C. Moldon, "Imaging of Objects Viewed Through a Turbulent Atmosphere"-Sc.D. thesis, Department of Electrical Engineering, Sept. 1968.
6. Jane W-S Liu, "Reliability of Quantum-Mechanical Communications Systems," Sc.D. thesis, Department of Electrical Engineering, Sept. 1968.
7. Richard Greenspan, "Information Transmission via Spatial Modulation of Waveforms," Sc.D. thesis, Department of Electrical Engineering, Sept. 1968.

8. Harold Heggstad, "Optimal Communications Through Multiple Scattering Media," Sc.D. thesis, Department of Electrical Engineering, Sept. 1968.
9. E. Bucher, "Error Mechanisms for convolutional Codes," Ph.D. thesis, Department of Electrical Engineering Sept. 1968.
10. E. Bucher, "Bounds on the Probability of Error of Systematic Convolutional Codes," accepted by IEEE Trans. on Information Theory.
11. R. G. Gallager, Information Theory and Reliable Communication, (John Wiley and Sons, Inc., New York November 1968.)